

J-PARC

RCS Injection issues

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J-PARC

Project X 2nd Collaboration Meeting
2009/9/11 ~12, FNAL.

(Presenter: David Johnson, FNAL)

Outline

1. General introduction.
2. **RCS injection and the painting scheme.**
3. Some results with painting injection study.
4. **Discussions on several key issues.**
 - 4.1 Design issues of the injection/injection dump lines.
 - 4.2 Closed orbit steering and aperture issues.
 - 4.3 Foil issues, temperature, lifetime, losses, etc.
 - 4.4 Beam loss in the injection area, estimation vs. reality.
 - 4.5 Electron collection issues.
 - 4.6 Internal / External Dump issues.
5. Near future upgrades.
6. Summary.

**J-PARC
(JAEA & KEK)**

Linac
181 MeV at present,
400 MeV with ACS
[600 MeV SCL in phase 2 for TEF]

**3 GeV Rapid Cycling
Synchrotron (RCS)**

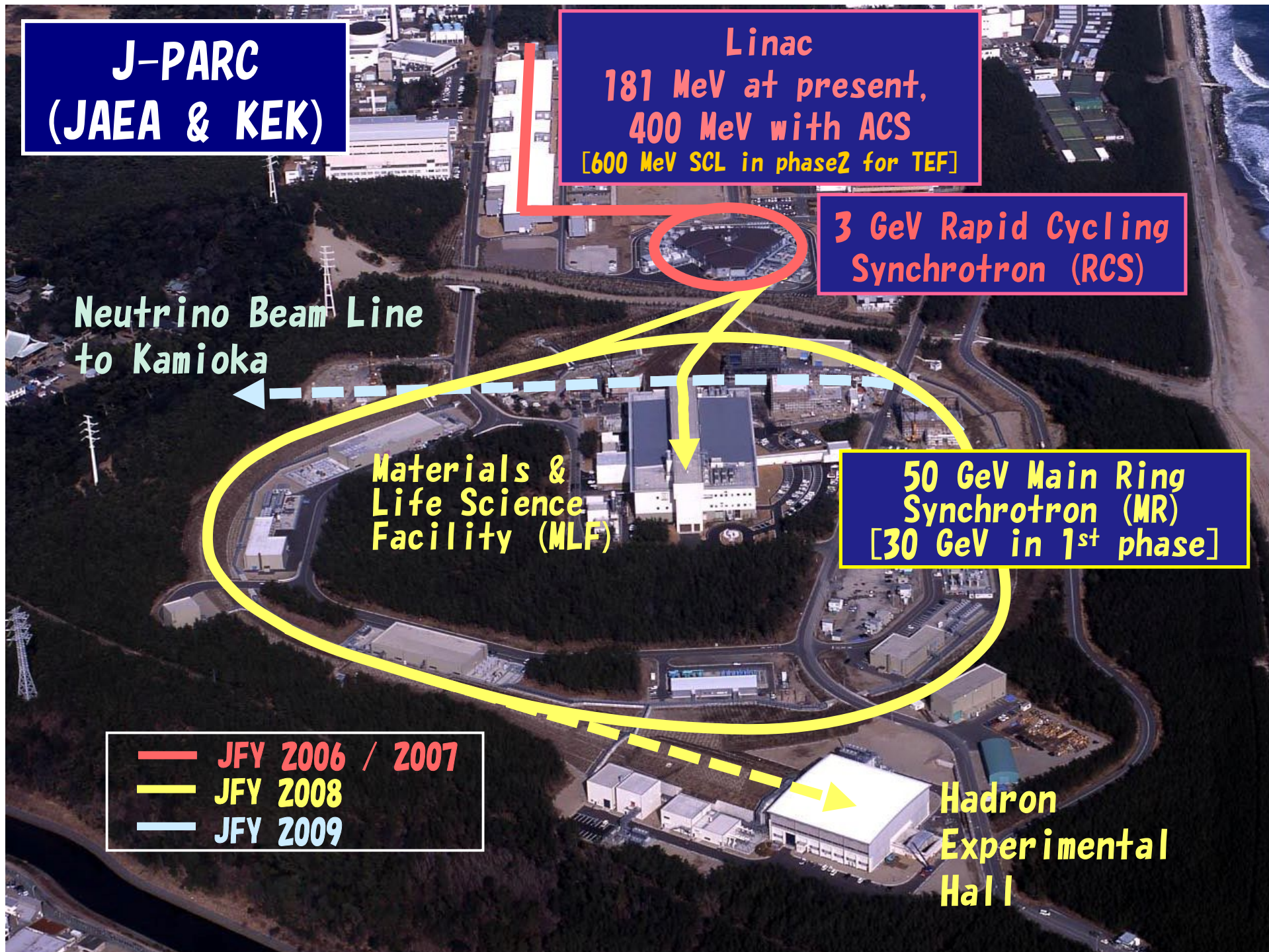
Neutrino Beam Line
to Kamioka

**Materials &
Life Science
Facility (MLF)**

**50 GeV Main Ring
Synchrotron (MR)
[30 GeV in 1st phase]**

— JFY 2006 / 2007
— JFY 2008
— JFY 2009

**Hadron
Experimental
Hall**



1. J-PARC Status at a glance

The J-PARC is a multi-purpose research facility covering the material and life science, nuclear and particle physics as well as nuclear engineering using a high power beam as high as 1MW.

At present, J-PARC is almost at the operation stage from its initial beam commissioning aspects.

LINAC: Operation stage → delivering almost stable beam to the RCS.

RCS: Operation stage → Stable beam to the MLF and MR.

To MLF: 20 kW, 25 Hz (max. 100 kW @ 25 Hz delivered in run #18)

To MR : 5 kW, Single shot / 1 Hz (for their initial commissioning)

MLF: Physics experiments already been started.

MR: Accomplished 30 GeV acceleration and slow extraction as well.

→ Physics experiments at the Nuclear and Particle Physics Facility are about to start.

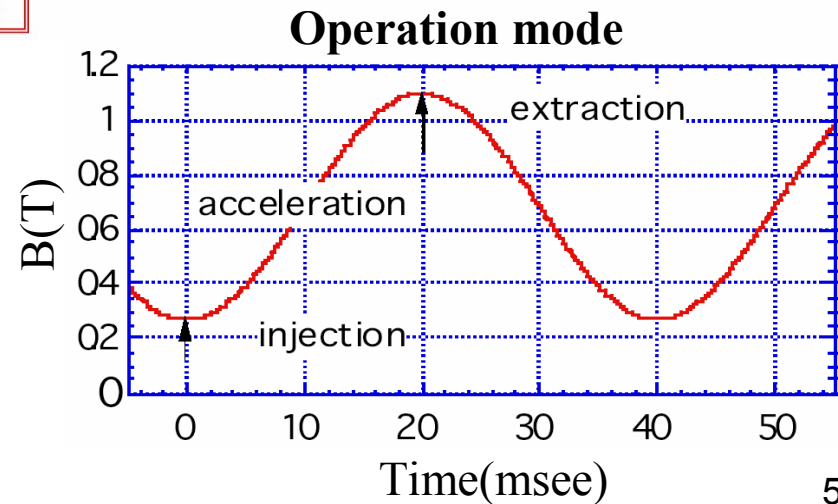
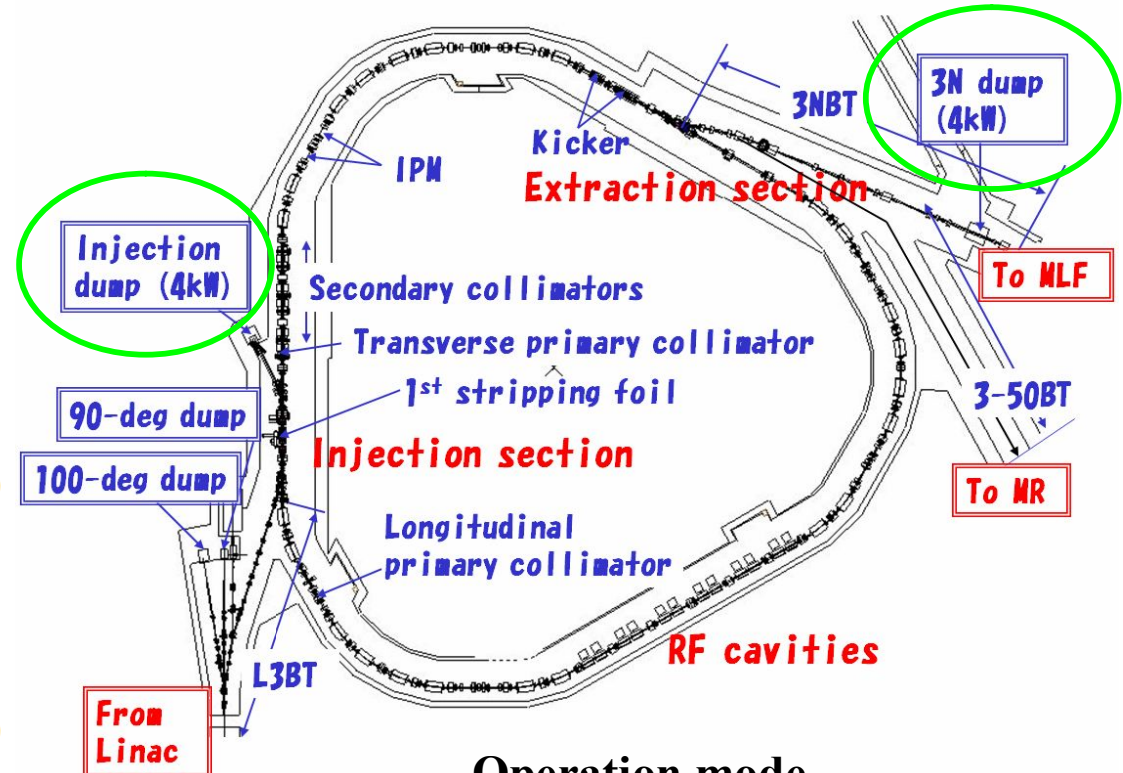
→ Fast extraction and neutrino production also been succeeded in April, 2009.

1. RCS

Design parameters

Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
No of bunch	2
Injection energy	181 MeV (400 MeV with ACS)
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	2.5×10^{13} - 5×10^{13} (8.3×10^{13} with 1 MW)
Output beam power	0.3 - 0.6 MW (1 MW with upgraded Linac)
Transition gamma	9.14 GeV
Number of dipoles	24
quadrupoles	60 (7 families)
sextupoles	18 (3 families)
steerings	52
RF cavities	12 (11 at present)

1st beam commissioned: October 2007



1. Some other basic parameters

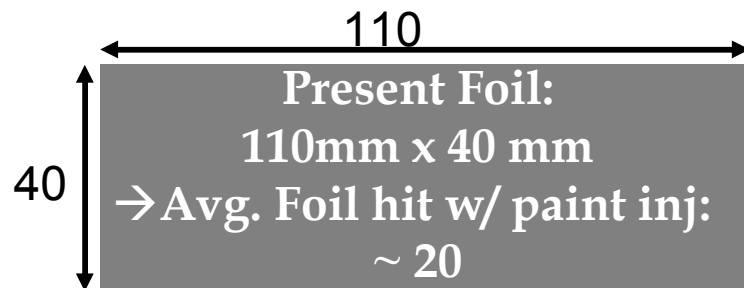
Emittance & Acceptance parameters

Injection beam:	$4 \pi \text{ mm mrad} + 0.1\% \Delta p/p$
Painting:	$216 \pi \text{ mm mrad}$
Prim. Collimator:	$324 \pi \text{ mm mrad} + 1\% \Delta p/p$
Sec. Collimator:	$400 \pi \text{ mm mrad}$
Physical acceptance:	$> 486 \pi \text{ mm mrad} + 1\% \Delta p/p$

Painting injection time: 0.5ms

→ 235 turns w/ 181 MeV at present

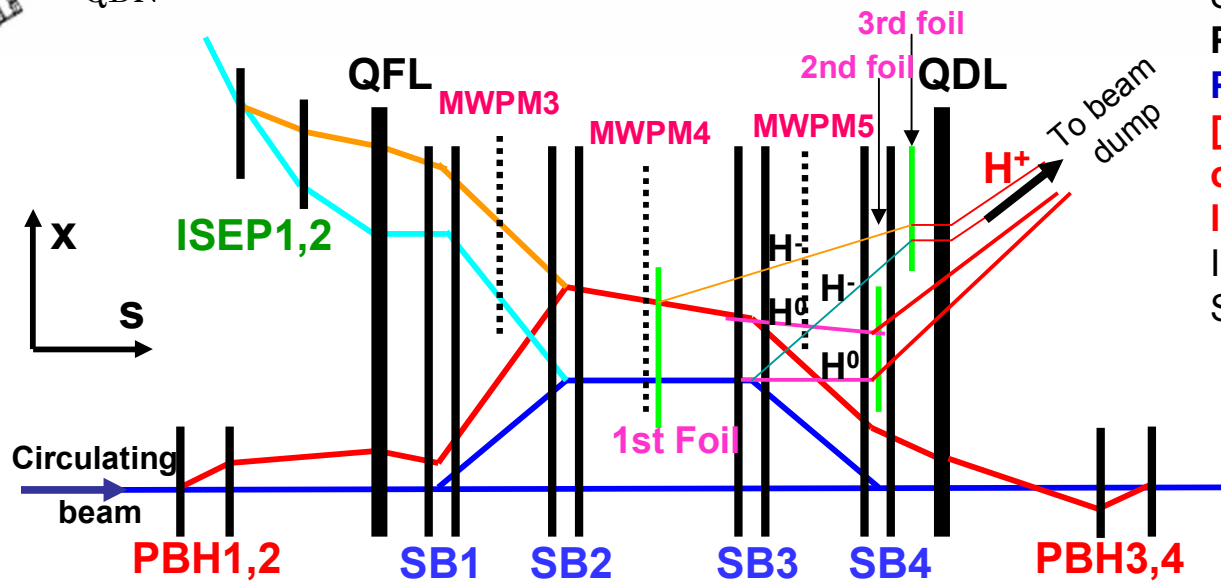
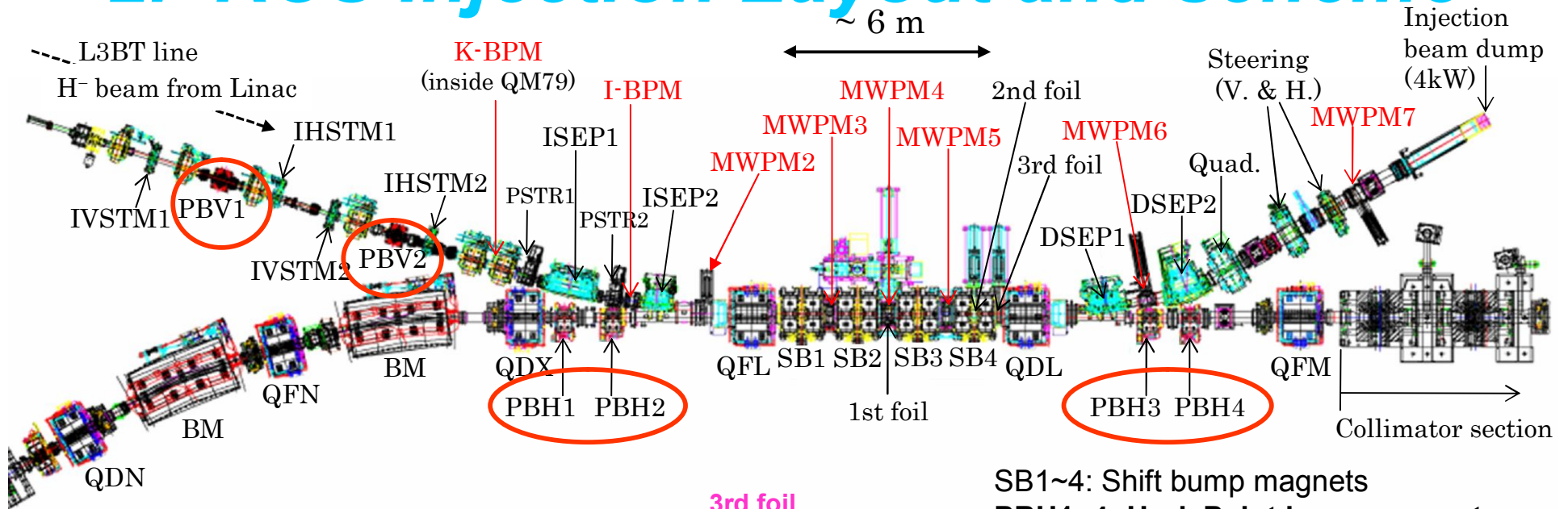
→ 308 turns w/ 400 MeV in future



Typical twiss parameters at the foil location

	Inj. beam	Circulating beam
α_x	-1.452	1.550
$\beta_x(\text{m})$	11.138	11.275
α_y	-0.400	-1.589
$\beta_y(\text{m})$	10.998	11.062
$\eta_x(\text{m})$	0.00	0.00
η'_x	0.00	0.00

2. RCS Injection Layout and scheme



SB1~4: Shift bump magnets

PBH1~4: Hori. Paint bump magnets

PBV1~2: Vert. paint bump magnets.

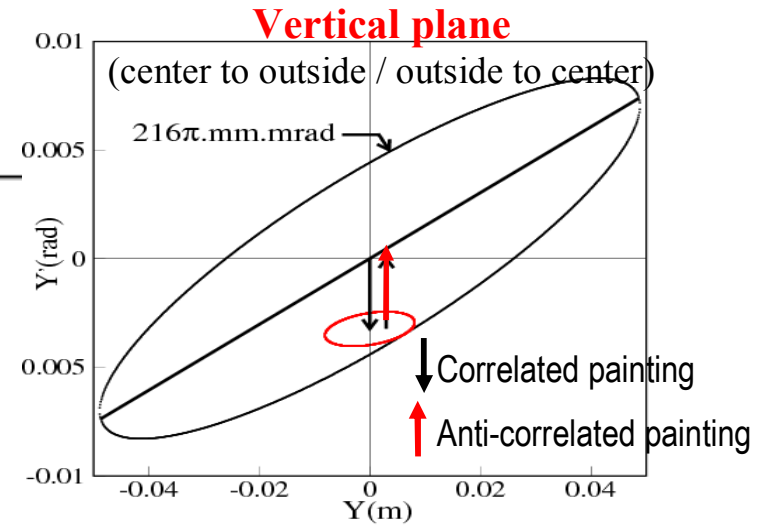
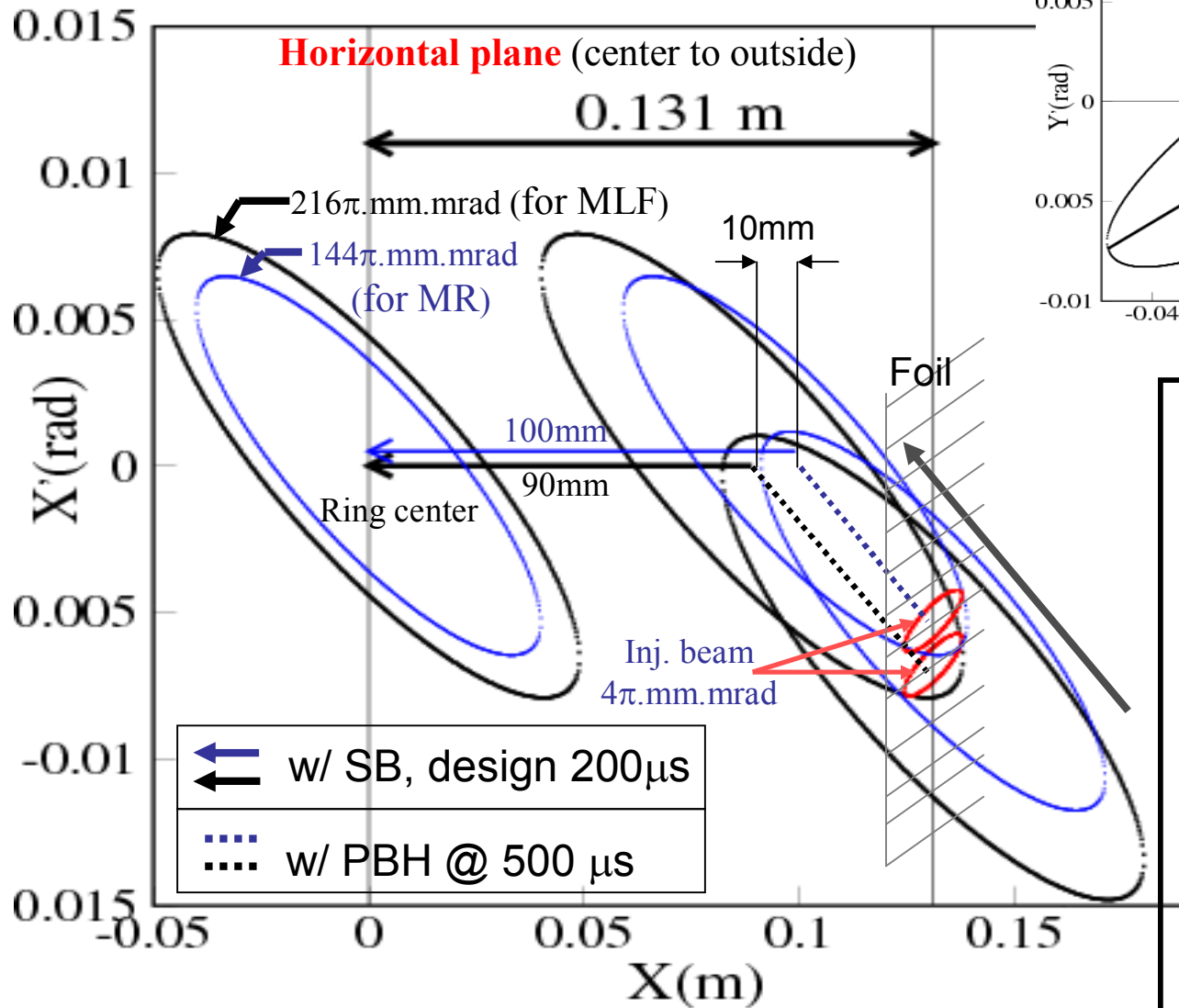
[Placed in the beam line because of 1) no space in the ring, 2) needs larger physical aperture]

ISEP1~2, DSEP1,2:

Septum magnets (DC)

— No painting (Center) injection
(H:90mm,0mrad ; V: 0mm, 0mrad)
— Painting injection
(Hori.:131mm(90+41), -6.5mrad)
(Vert: 0mm, -3.2mrad)

2. Painting Process



For MLF: 216 π mm mrad

$$X = 131 \text{ mm} \text{ (90 + 41)}$$

$$X' = -6.4 \text{ mrad}$$

Knobs for the Inj. beam:
ISEP1,2 + SB

For MR: 144 π mm mrad

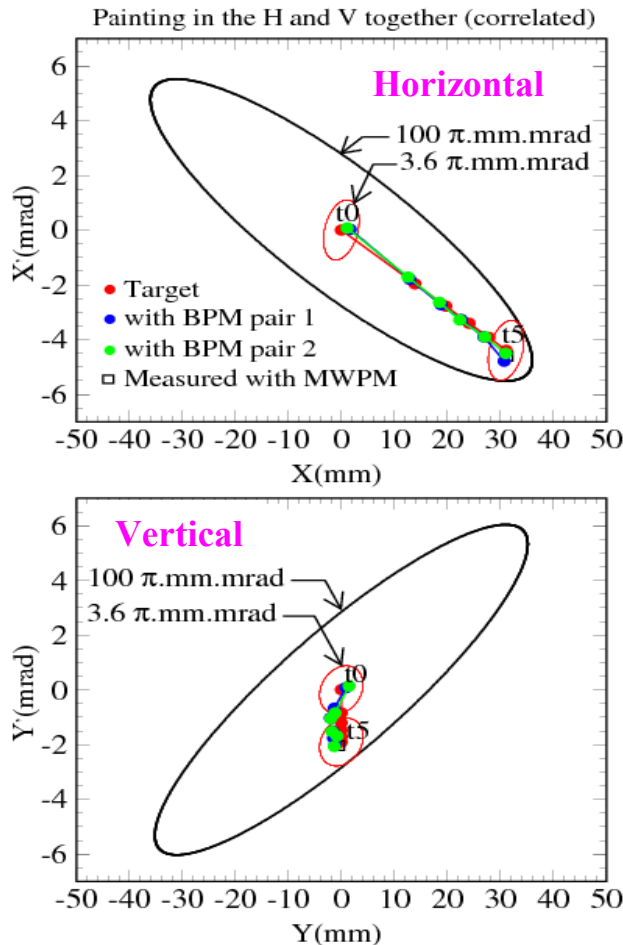
$$X = 131 \text{ mm} \text{ (100 + 31)}$$

$$X' = -4.9 \text{ mrad}$$

Knobs for the inj. beam:
ISEP1,2 + SB + PSTR1,2

3. Transverse painting injection study

Painting injection study was able to perform comparatively earlier stage of the beam commissioning.



Done explicitly for a painting area of 100 π mm mrad.

Phase space diagram at the top excitation level and then footprint at the 6 different timing was extracted by using circulating orbit measured turn-by-turn with a BPM pair.

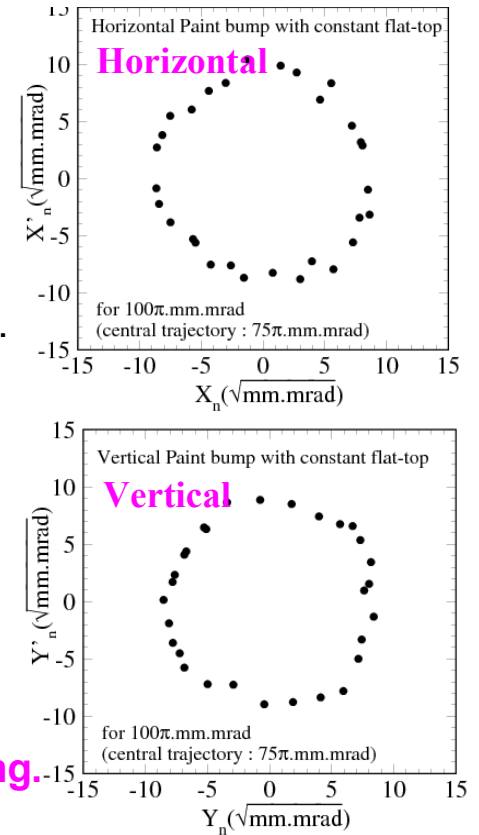
$$\begin{bmatrix} X_{\text{BPM}} \\ X'_{\text{BPM}} \end{bmatrix} = \begin{bmatrix} \mathbf{M}^n \\ \mathbf{M} \end{bmatrix} \begin{bmatrix} X_{\text{foil}} \\ X'_{\text{foil}} \end{bmatrix}$$

\mathbf{M}^n : n turn transfer matrix

\mathbf{M} : Transfer matrix from foil to the BPM

- Well Calibrated the top excitation level
- Justify decay patterns in different timing.
- Go to larger painting areas by scaling.

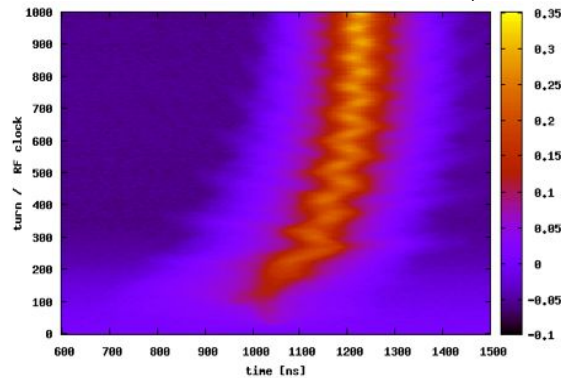
PB w/ Constant flat-top



For more detail: [P.K. Saha et. al.](#)
PRST - AB 12, 040403 (2009)

3. Longitudinal Painting injection study

No painting
Fundamental RF only



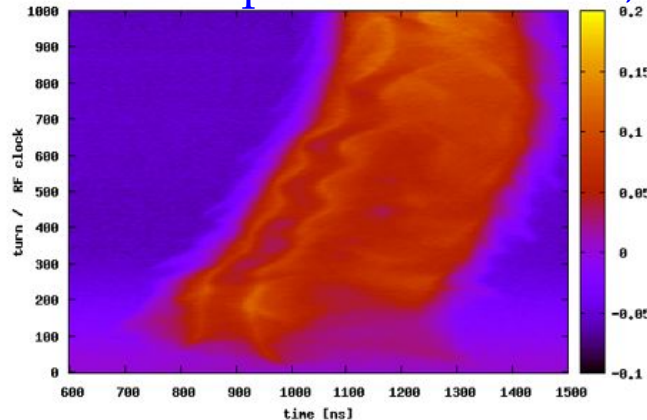
Bunching factor:
At the end of
injection: ~ 0.2



Momentum offset ; -0.2%

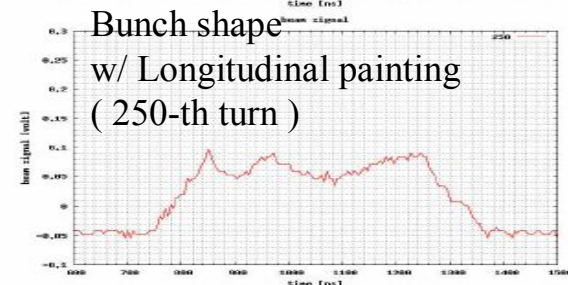
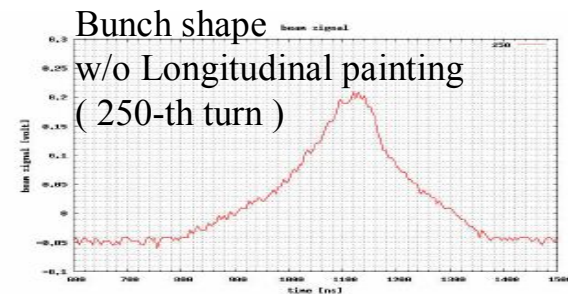
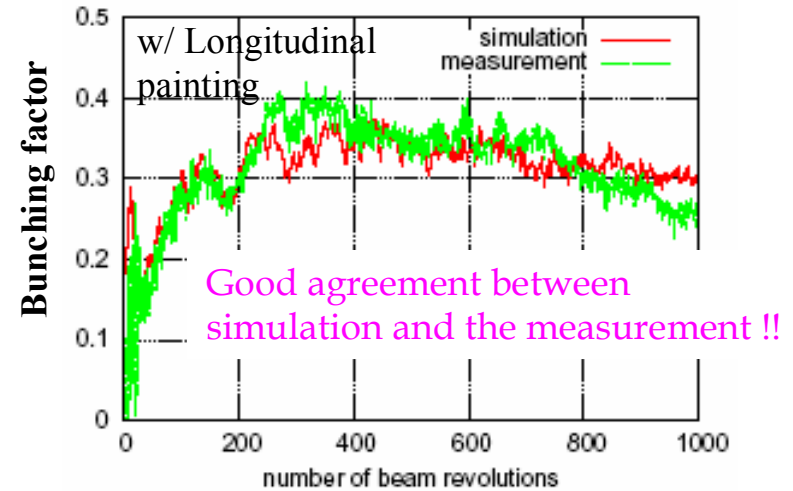
2nd harmonics to the fundamental; 80%

Phase sweep of 2nd harmonic ; -80 deg



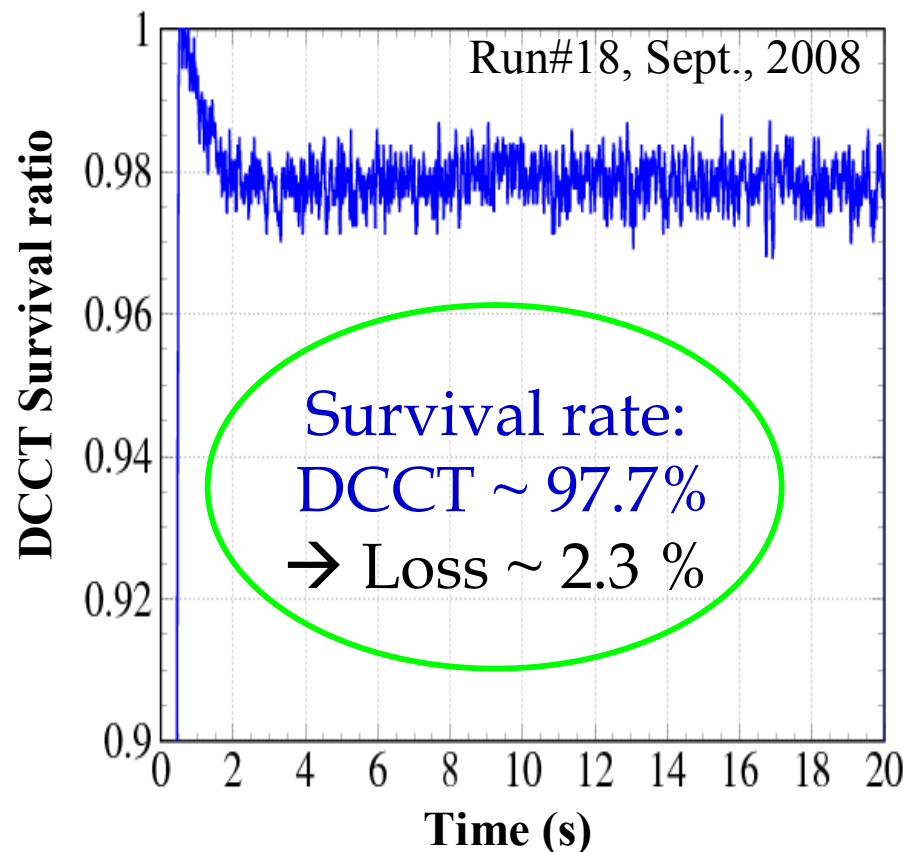
Bunching factor
At the end of
injection: ~ 0.4

F. Tamura et. al.
PRST - AB 12, 041001 (2009)



3. Beam power achievement (1)

w/ center injection (no painting)

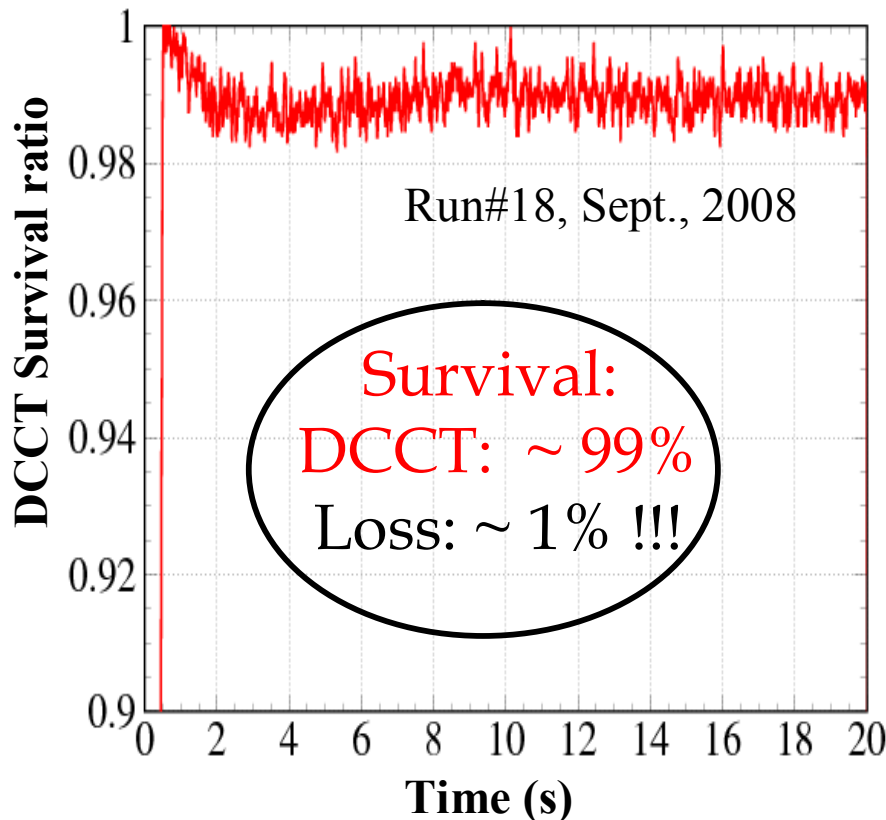


Linac peak current: 15 mA
Macro pulse width: 0.5 ms
Chopping width: 420 ns
2 bunches, 25Hz
70 sec operation due the limitation
of the dump

Output:
3N-Dump CT: 1.77×10^{13} ppp
→ 213 kW !!!

3. Beam power achievement (2)

w/ painting injection
(Transverse + Longitudinal)



Linac peak current: 15 mA
Macro pulse width: 0.5 ms
Chopping width: 600 ns
2 bunches, single shot

Output:

3N-Dump CT: 2.58×10^{13} ppp
→ 310 kW !!! (if run w/ 25Hz)

4. *Discussions on several issues*

- Design issues of the injection line, injection dump line.
- Closed orbit steering and aperture issues
- Foil issues, temperature, lifetime, losses, etc.
- Beam loss in the injection area, estimation vs. reality.
- Electron collection issues.
- Internal / External Dump issues.
- Near future upgrades.

4.1 injection/injection-dump lines, design issues:

Design injection Beam emittance (4σ) : 4π mm mrad @ 400 MeV
: 6π mm mrad @ 181 MeV

Measurement @ 181 MeV w/ 5 mA peak: $\sim 5 \pi$ mm mrad (4σ)
→ but long tail w/ higher peak current was observed

Except minor changes in some places at the last moment, physical aperture of the injection/injection-dump lines were designed to be larger than beam stay clear (BSC) w/

Half-width BSC = $\text{Sqrt}(\beta * \varepsilon) + \eta (\Delta p/p)$

+ orbit stability + β, η fluctuations + ring COD fluctuation (3mm + 3mm + 3mm)
Where, $\varepsilon = 30 \pi$ mm mrad and $\Delta p/p = 0.3\%$ were considered.

✂ Experience: Loss monitor signal observed at one tight point with a peak current of 30 mA. Probably because of insufficient tuning of the beam for that run!

4.2 Closed orbit steering and aperture issues

Horizontal beam position w/ ΔR -BPM

— before RF frequency tuning

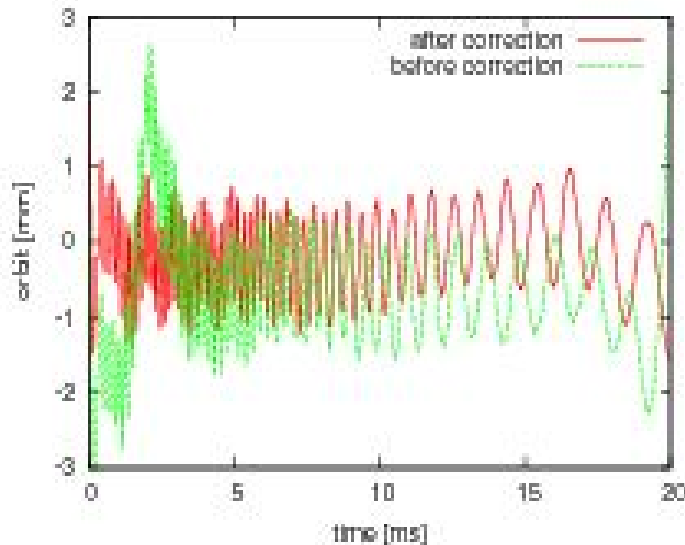
— after RF frequency tuning



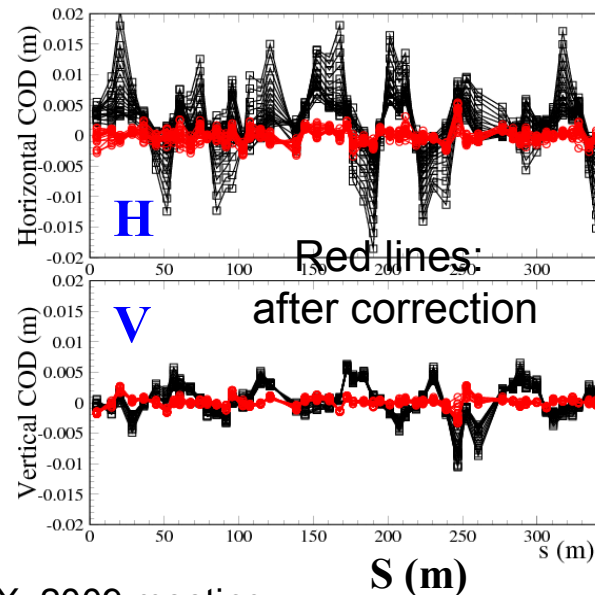
Once done in the beginning of the cycle,
no online radial feedback loop needed
throughout the cycle !



Excellent stability of
the bending magnets !!



Remaining COD corrected (red lines)
by using Steering magnets



See for detail:
H. Hotchi et. al.
PRST -AB 12, 040402
(2009)

**No practical limitations on
aperture issues so far
connecting to the
closed orbit and steering !**

4.3 Foil issues, temperature, losses, etc..

Used foil so far: Carbon foil made by I. Sugai.

Official thickness: $260 \pm ? \mu\text{g}/\text{cm}^2 \rightarrow$ Charge exchange eff $\sim 99.9\%$
(design thickness w/ 181 MeV: $200 \mu\text{g}/\text{cm}^2$)

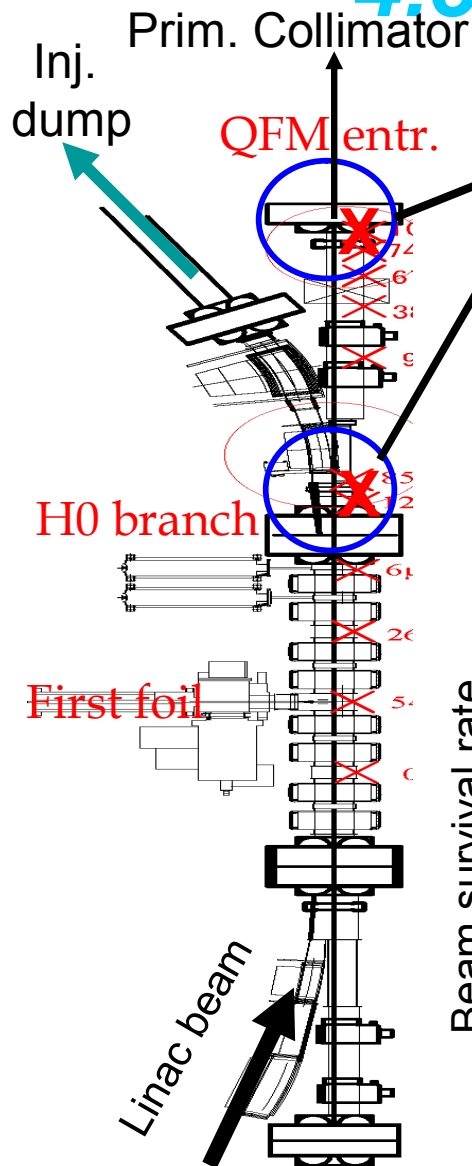
No particular issue except uncontrolled beam loss in the injection area, which is the main concern foil at present.
Foil thickness is one key issue \rightarrow under study

HBC foil with different thickness will be available from the next run.

No device made available so far to measure foil temperature.
 \rightarrow Not yet considered seriously / no space to install any device?
With design operation (inj. beam power of 133 kW @ 400 MeV),
foil temperature (calculated): $\sim 1,600\text{K}$

✂ *Last foil exchange: Sept. 2008, \rightarrow 8 runs until May, 2009.*
Although mainly w/ 20kW operation, no sign of practical damage!

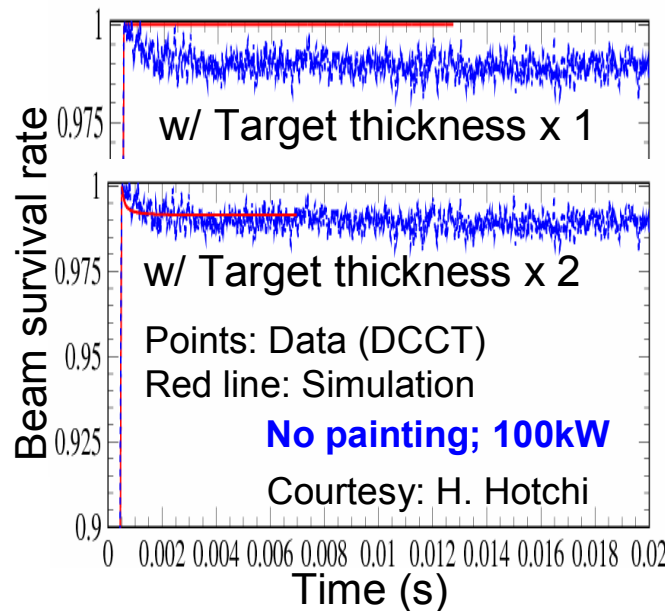
4.3 Foil issues (cont.) beam losses



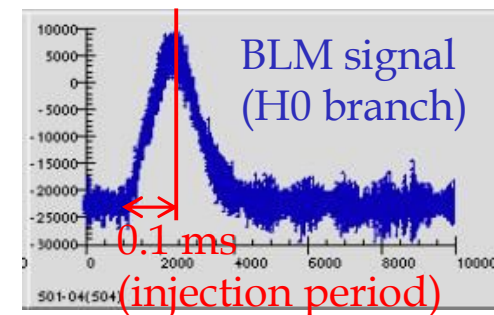
X Two unexpected hot points in the injection region
 → Higher levels in the inner (ring) side.

Main sources (assumptions):

1. Large foil scattering in case foil thicker than expected.
 → Under investigation
2. QM & BPM misalignment → BBA data taken.
 → Further study is in progress.



✗ w/ recent 20kW operations (transverse painting on),
 Residual radiation levels (contact) in those two areas ~0.2 mSv/h!!
 → **expectation: 0.01 mSv/h! to meet the requirement at 1MW (1mSv/h).**



4.4 Beam loss in the injection area: estimation vs. reality

w/ recent operation condition:

Injection: 1.2 kW, extraction: 20kW ~1% of the design.

- Neutralization rate of the H- : 10^{-12} → No residual radiation in the injection line
- H0 excited state loss: 0.1W at Max. → No residual radiation near foil region
- Decay of H0 hits the outer side of the H0 branch but not the inner side, where residual radiation level is high (see. last slide)

*Foil scattering probably the main issue and at present struggling with foil thickness.
Foil until now is day1 type → made with a bit thicker for safety.*

Recently installed 6 HBC foils: 100 ~600 $\mu\text{g}/\text{cm}^2$. Expected error in thickness: $\sim \pm 5\%$!

→ **Experimentally we will try to get the thickness of the foil used so far!**

→ **Can be connected to more realistic estimation related to this issue!**

Foil Hit issue:

20 kW opr. w/ center injection (no painting): Avg. hit ~120

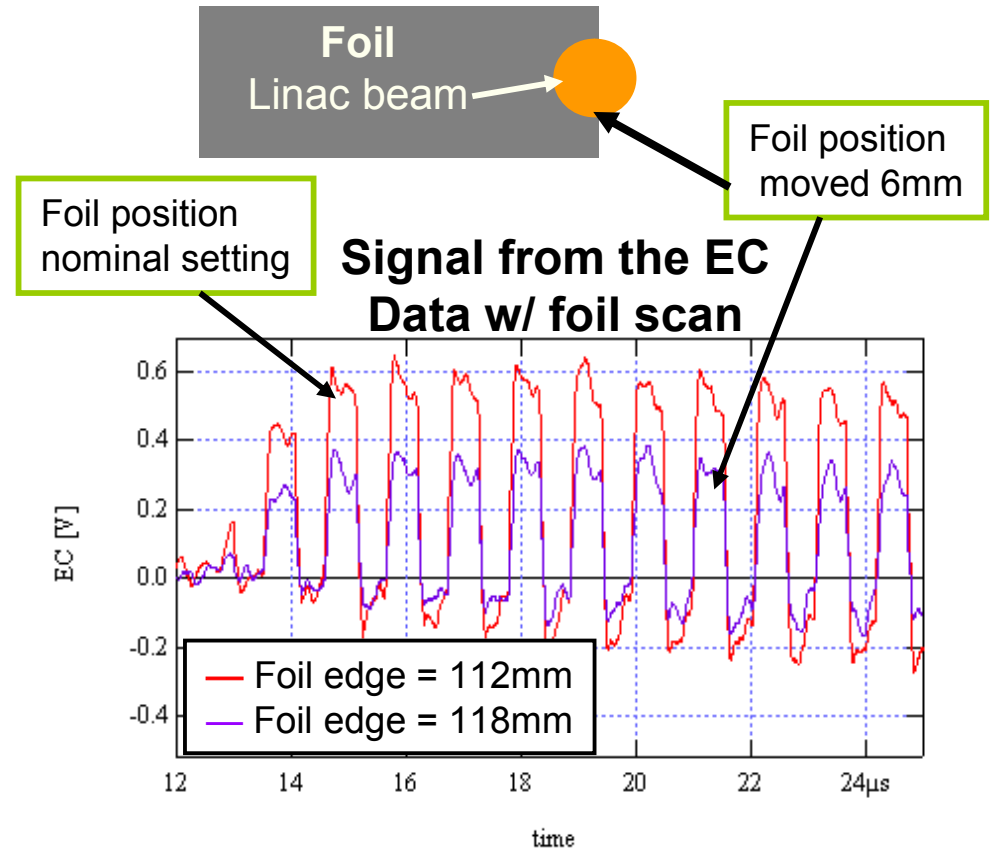
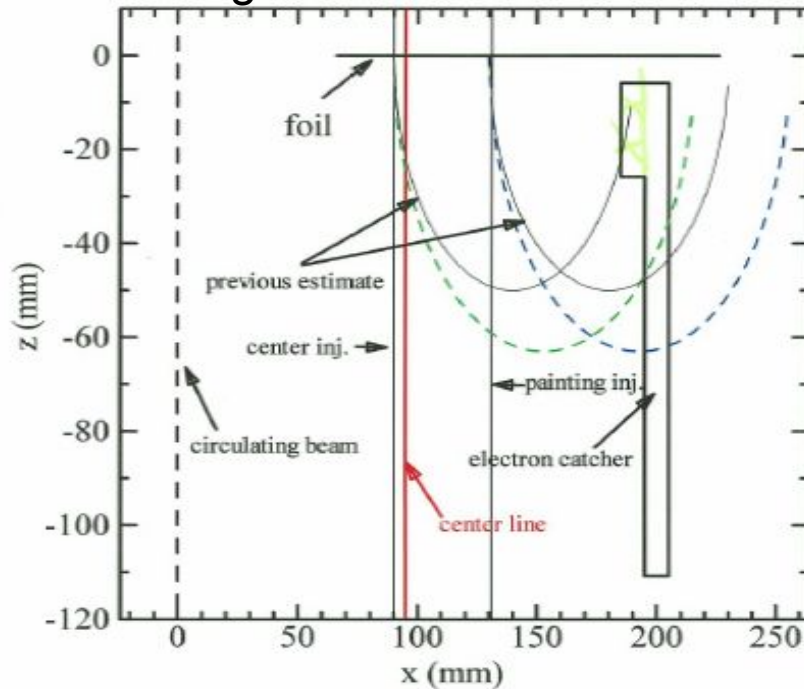
20 kW opr. w/ painting (150π) injection: Avg. hit ~17 → Reduction ratio ~ 1/7

→ **Reduction of residual radiation ~ 1/5 → Close to expectation!**

4.5 *Electron collection issue*

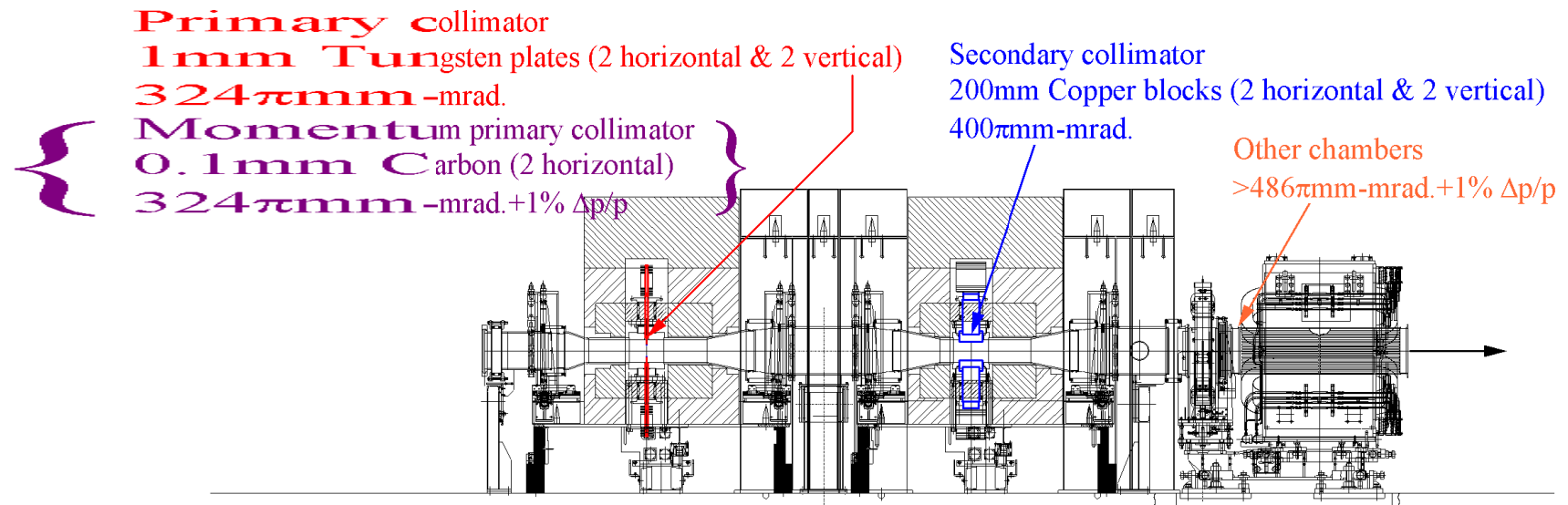
→ Electron catcher → working fine !!

Design of the electron catcher



Beam: 50 μ s (24 intermediate pulses)
Plotted here for a half

4.6 Internal / External Dump issues



Internal Dump (Collimator) : Two stage collimation system.

Design criteria:

- i) High beam loss localization (1 W/m rest of the ring)
 - ii) Enough shielding, iii) Easy maintenance, etc...
- } **Limit: 4 kW**

Estimated loss with recent simulation introducing realistic parameters experienced through the beam commissioning up to now ~ 1 kW

Experience: Working fine and no sign of technical limit as operating only w/ 20kW.

4.6 Internal / External Dump issues

External dumps

■ Injection Dump:

Used for Un-stripped (H^-) /partial stripped (H^0) beams

Limit: 4 kW → Limited by the space.

Waste beam at design power: $\sim 0.4 \text{ kW} \ll \text{Limit}$

No practical limit faced so far!

But only 15m away from the injection point.

Back scattering events from the dump w/ design power may arise any problem?

■ 3N Dump: Used for RCS beam study (181 MeV \sim 3 GeV)

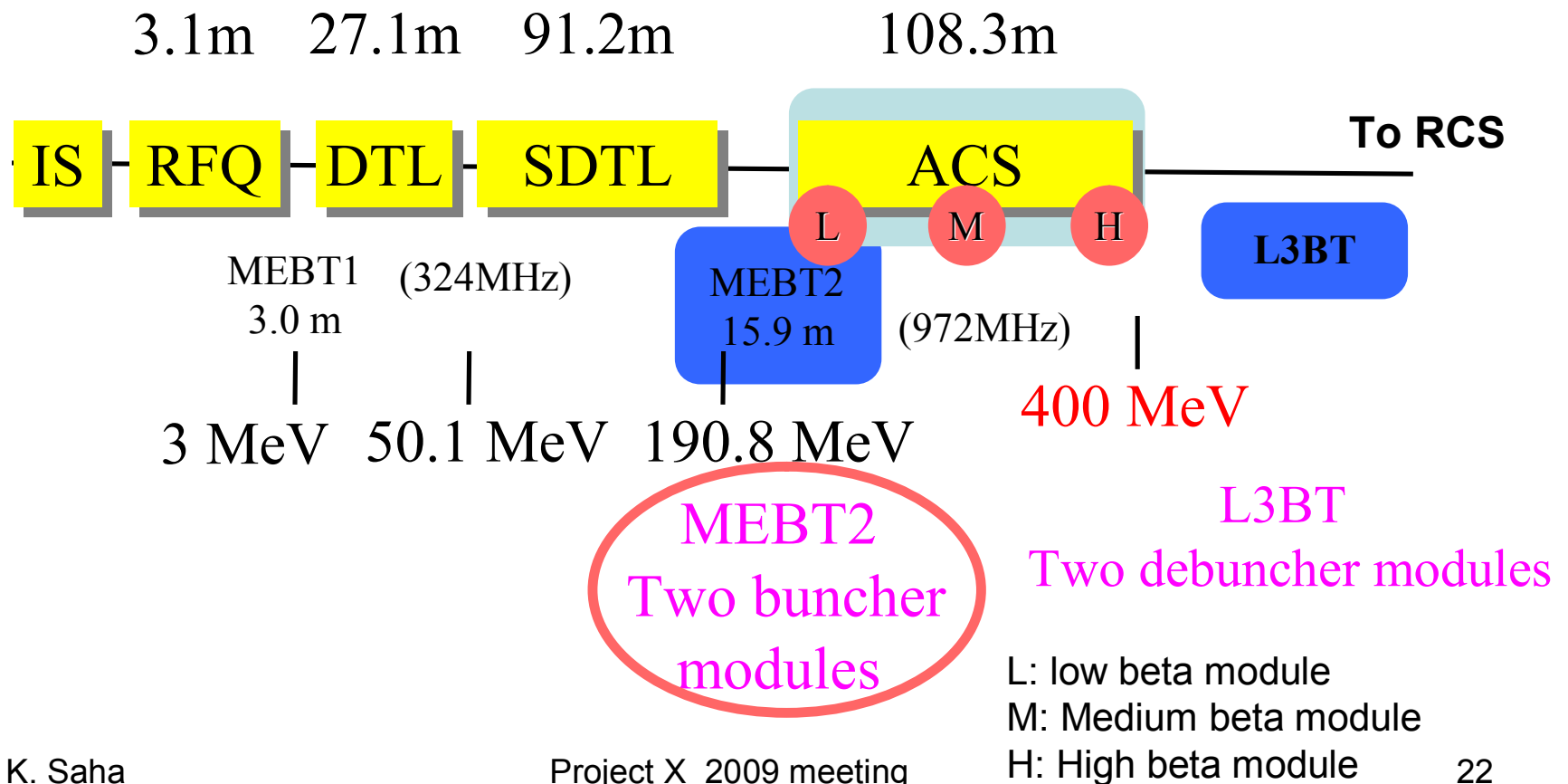
Limit: 4 kW → also limited by space.

→ Duty is low but better if one has higher availability!

5. Near future upgrades (1)

181 MeV Linac → **400 MeV** with ACS

ACS (Annular Coupled Structure) Linac
21 accelerating modules



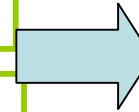
5. Some other necessary upgrades (2)

Upgrade of the **Linac** front end:

1. **Ion source**: 30mA peak → **50 mA** peak
 2. **RFQ**
 3. Upgrades of some monitor systems
- A prototype of 50 mA RFQ has been fabricated and test with low power
- R&D works has been started.

RCS : Injection bump systems

1. **Shift bump**: 20kA → 32 kA
 2. **Horizontal Paint bump**: + ~50%
 3. Injection pulse steering magnets to change the painting area pulse to pulse for the MLF and MR beam (see slide #7).
 4. Upgrades of some monitor systems.
- Some of the R&D works has been started and a detail schedule is under construction.



Linac:

Energy: 400 MeV,
peak current: 50mA
Chopping (duty) 0.56
→ **133 kW**

RCS:

25Hz, 2 bunches
Energy: 3 GeV
→ **1 MW**

6. *Summary*

Except one unexpected issue concerning two hot points (beam loss) near the RCS injection area, overall situation with the injection system/scheme is satisfactory.

Concerning that issue, we are in a stage of performing detail systematic studies in both simulations and using beam.

Hope to find out the sources soon, which can lead us to meet the design criteria with the present operation condition and thus connect to a smooth upgrade of the RCS injection system for the 400 MeV.

Optimization of beam halo with higher peak current might appear as an issue.